Accelerator Simulation Programs for High Intensity Proton Beams at Fermilab

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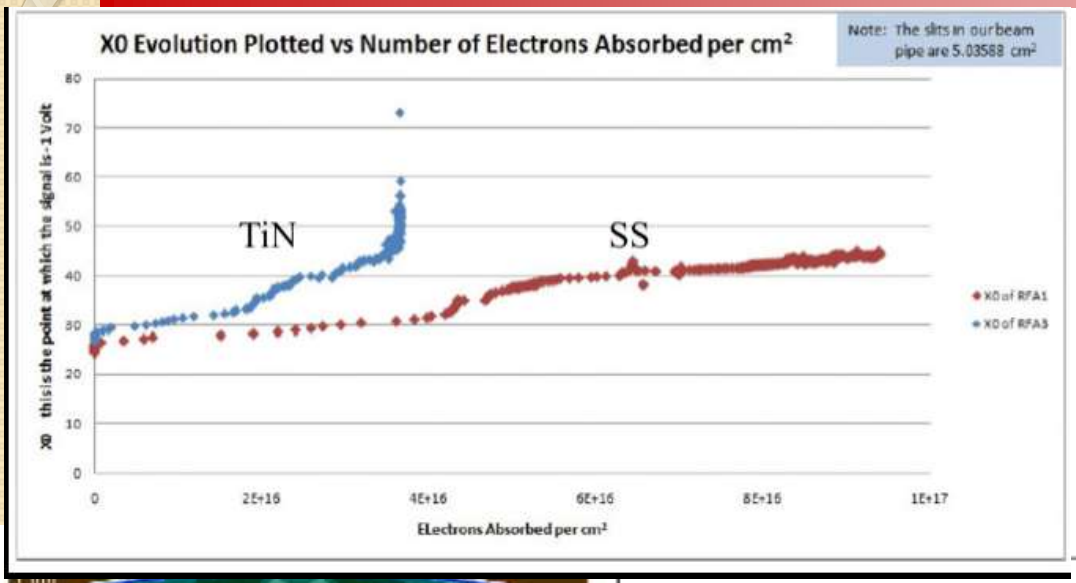
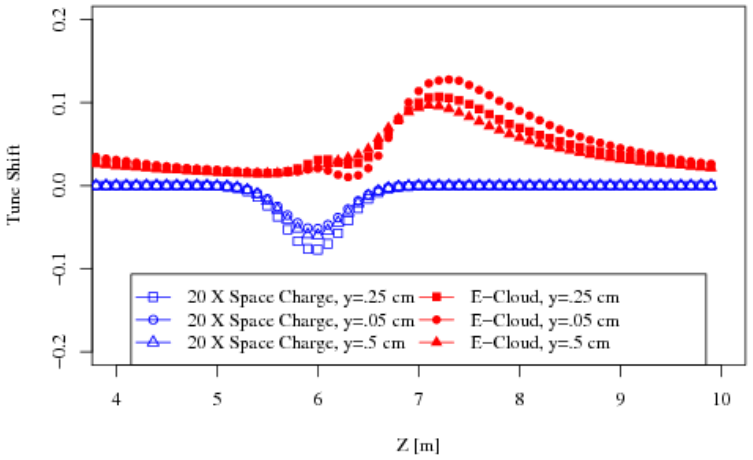
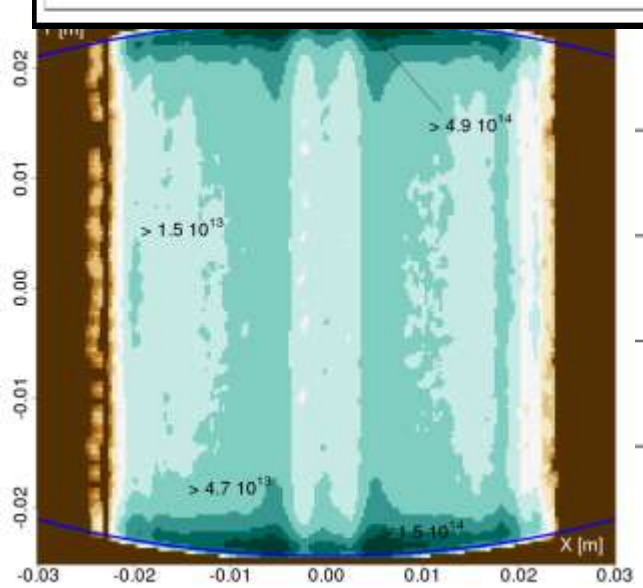
Very Broad Scope of Simulations

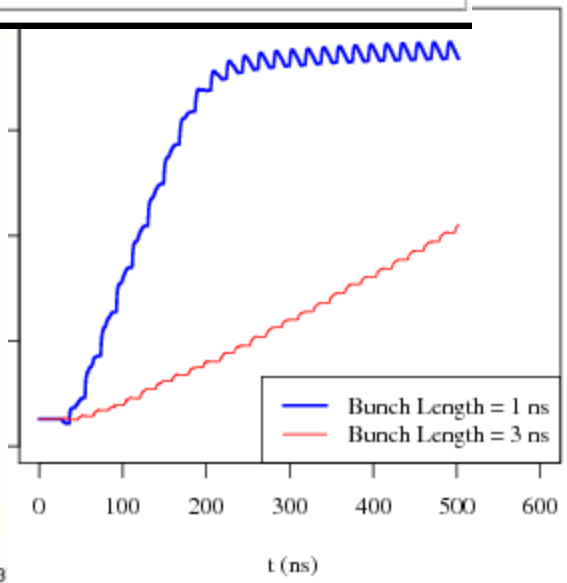
- Beam dynamics simulations
  - Injection, PrX linac, MC rings, SCC, e-cloud, HP RF, hollow e-beam collimation, beam loading and slow extraction, cooling
- Energy deposition simulations
  - Targetry, radiation levels, collimation
- Development of simulation tools
  - SYNERGIA, MARS, OPTIM, GEANT4/BL, etc

Electron cloud simulations



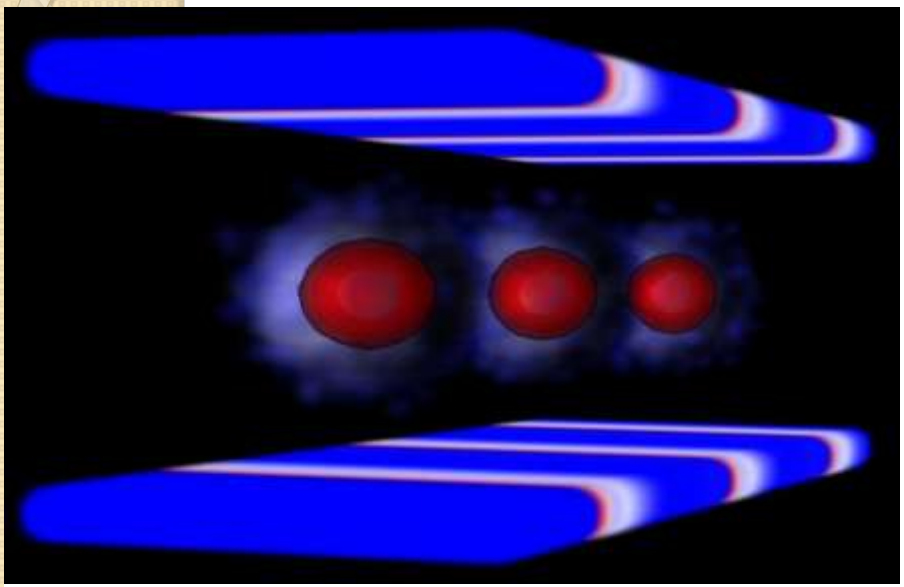


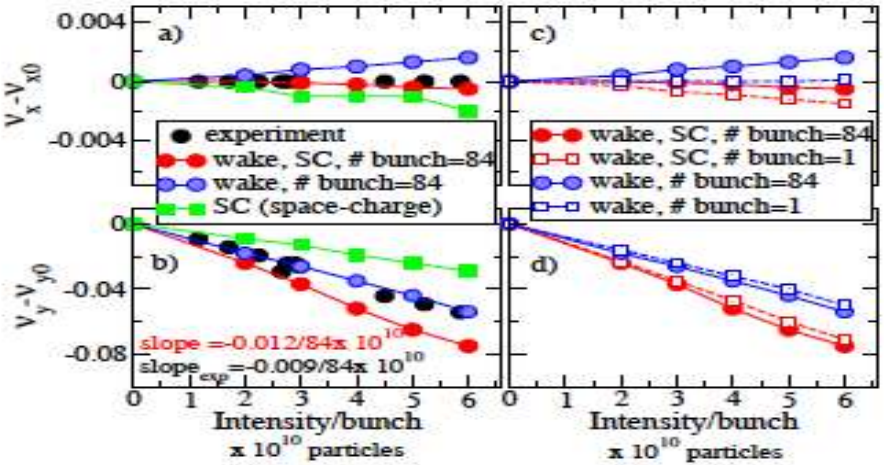


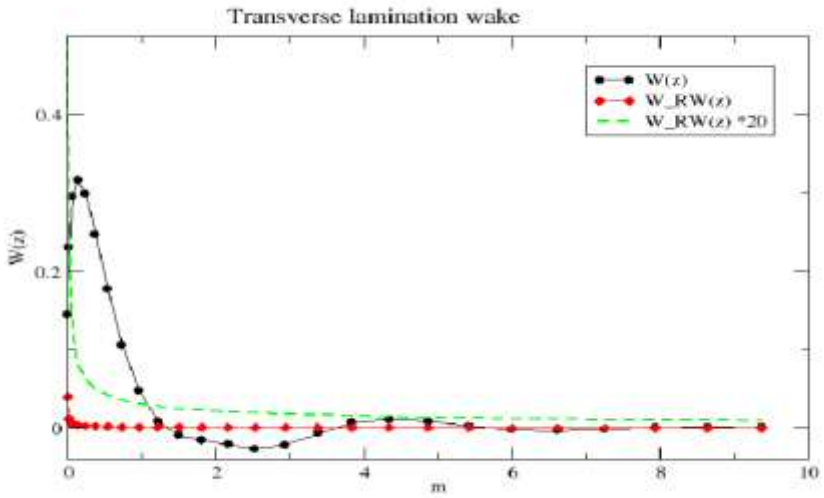


- Effect observed in MI, important for Pr-X, MC, etc
- Simulate e-production, coating, accumula-tion, thresholds, tune shift, diagnostics, other effects
- Variety of codes: VORPAL, POSINST, SYNERGIA, ORBIT
- P.Lebrun, R.Zwaska, P.Spenzouris, et al.

Impedances and instabilities

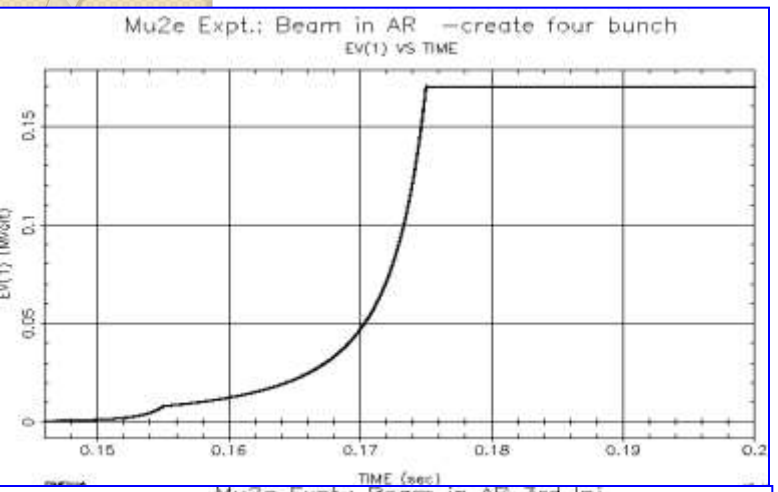


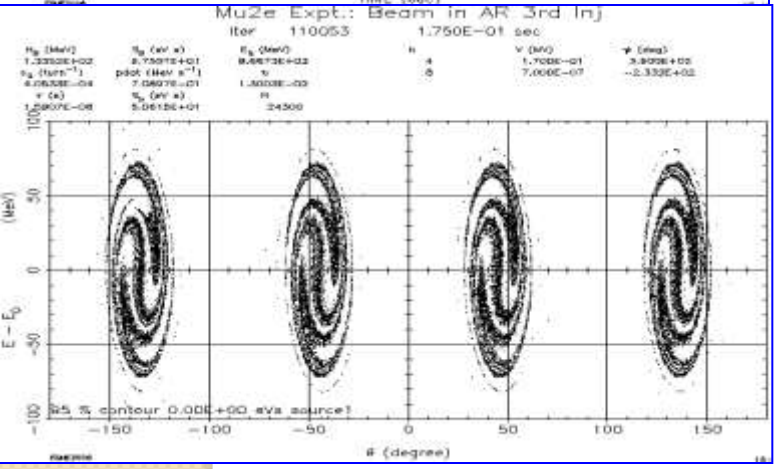


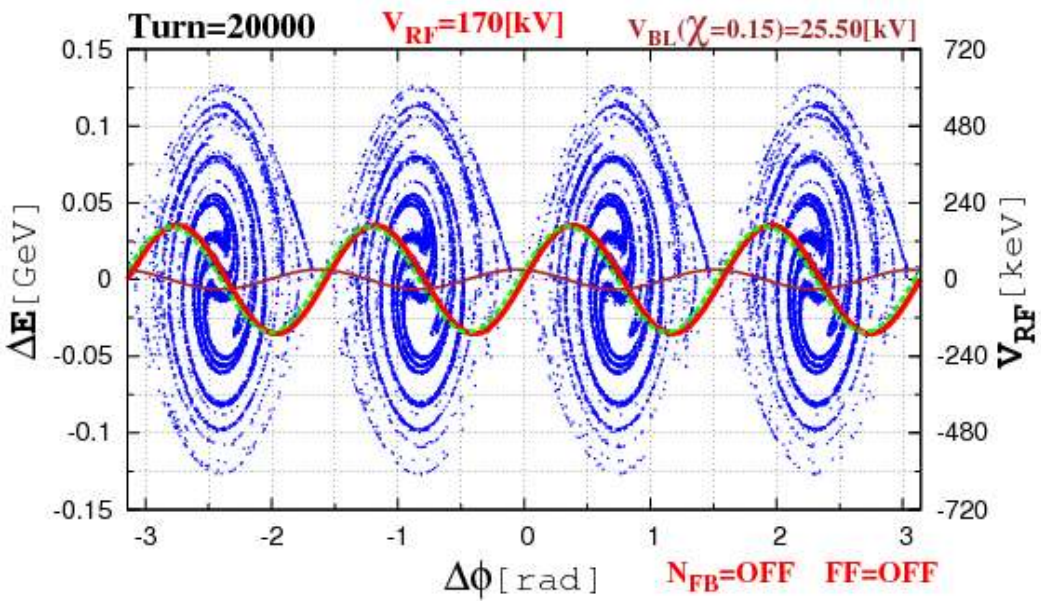


- Rather complicated case of wakes in the laminated structures – e.g. Booster magnets
- Simulate wake-functions, geometry effects, dependencies, effects on beam (observable such as tune and coupling shift with intensity, etc)
- Another non-trivial wake – due to beam-beam in 36 Tevatron bunches
- A.Macridin, J,Amudsen, P.&L. Spenzouris, E.Stern, A.Valishev, et al.

Longitudinal proton dynamics

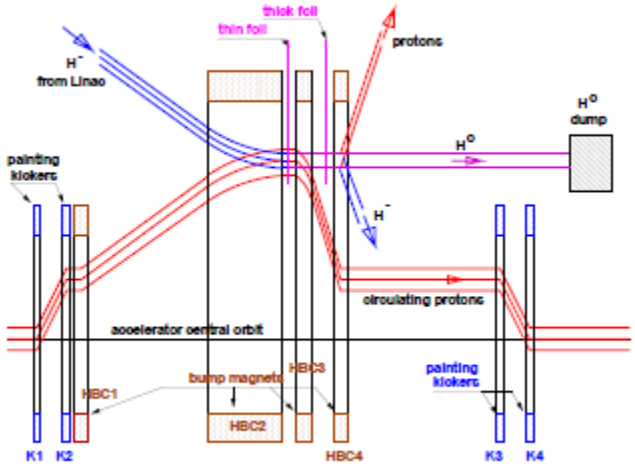


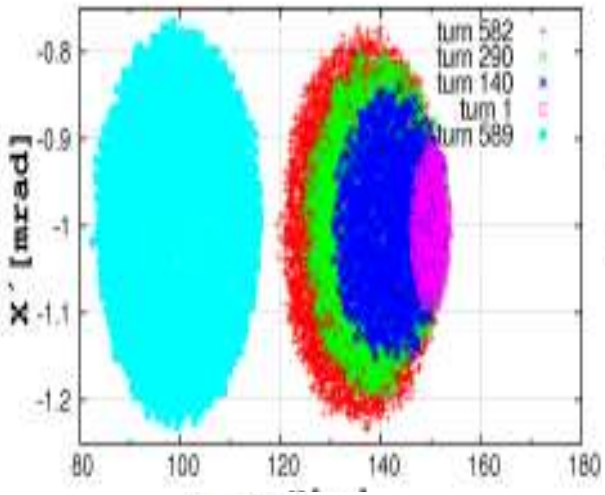


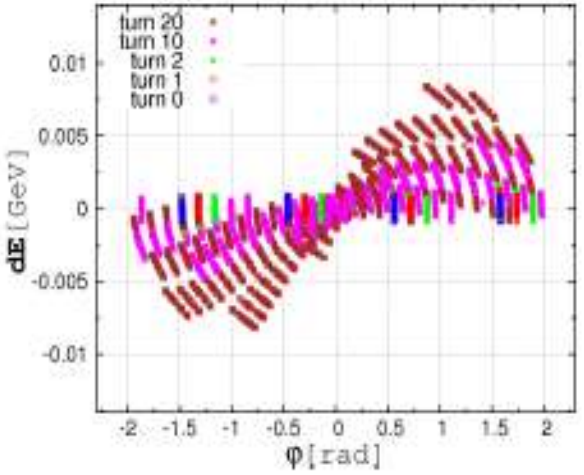


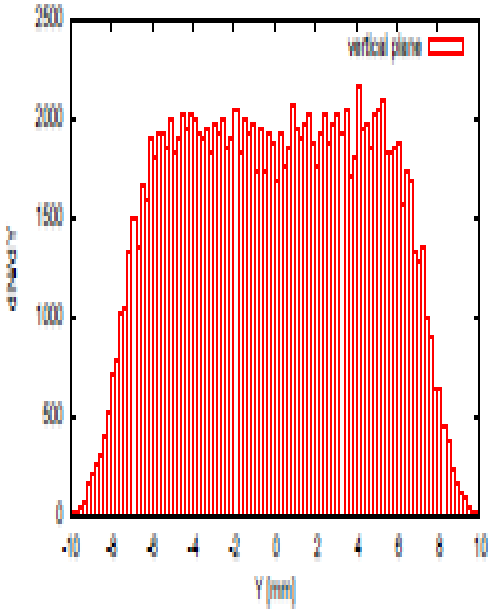
- Longitudinal dynamics due to RF voltage induced by cavity/other impedance → effects in bunch formation and intra-bunch proton poplation
- Requirements on the impedance; proposed countermeasures, simulations of the feedback feedforward effects
- ORBIT, ESME
- L.Vorobiev, C.Bhat, V.Balbekov, K.Seiya, et al.

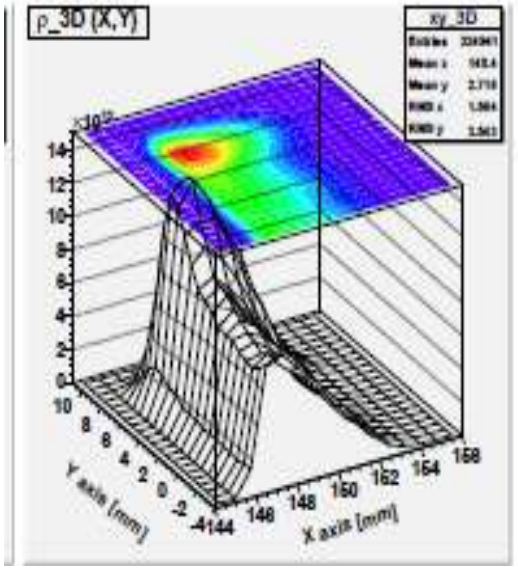
Injection painting: Project X





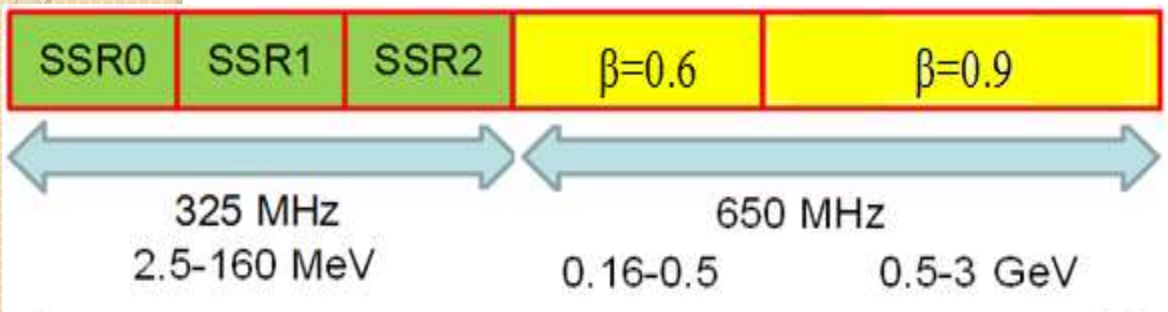


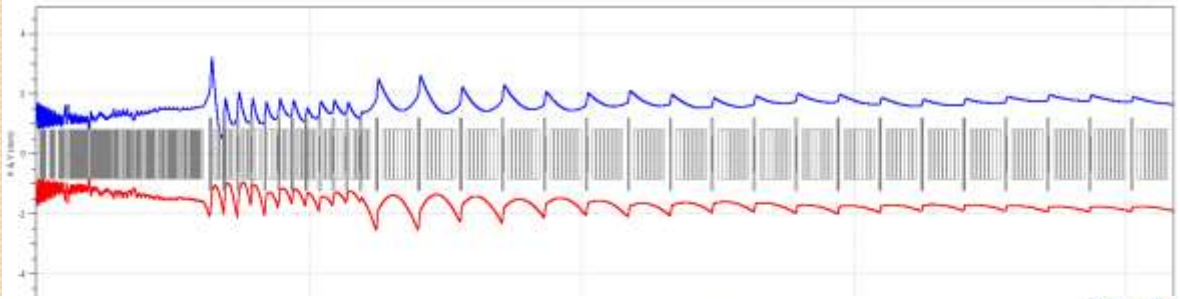


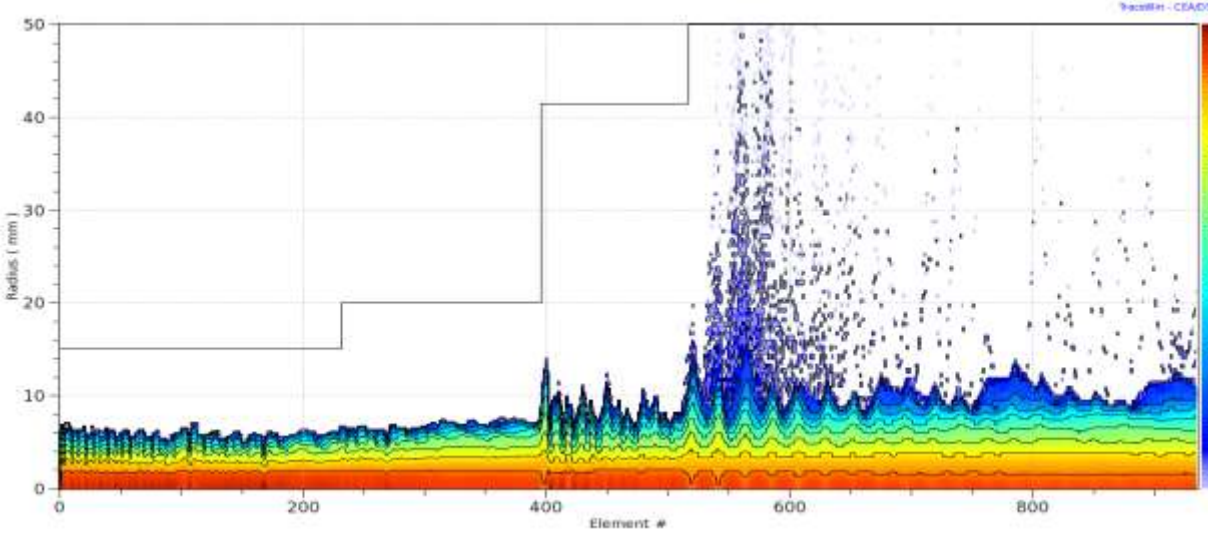


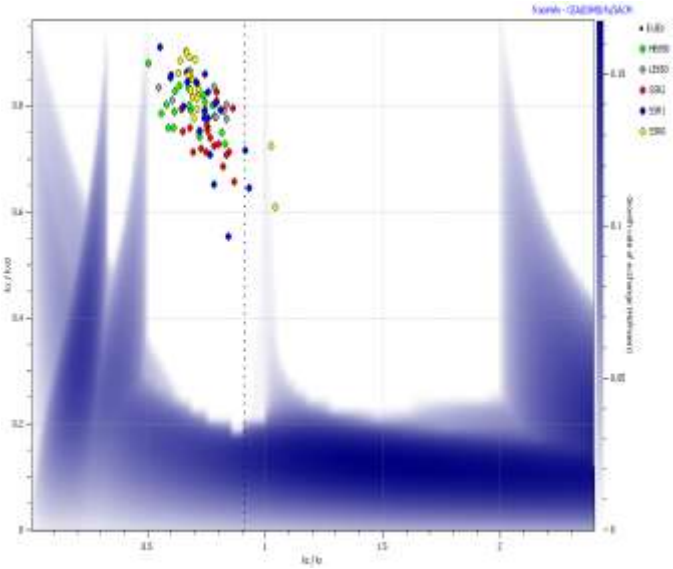
- Multi-turn injection method for injection of Pr-X beam into Recycle
- Simulations of optimal painting pattern, stripping foil temperature, space-charge considerations, etc
- 6D: transverse and longitudinal dynamics
- A.Drozhdin, I.Rakhno, L.Vorobiev, D.Jophnson, et al.

Beam dynamisc and losses in Pr-X linac



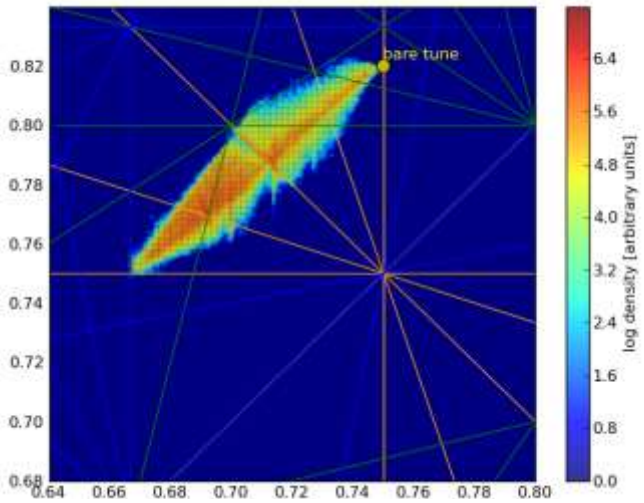


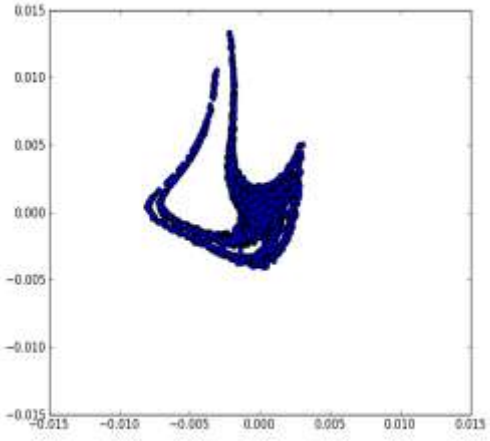


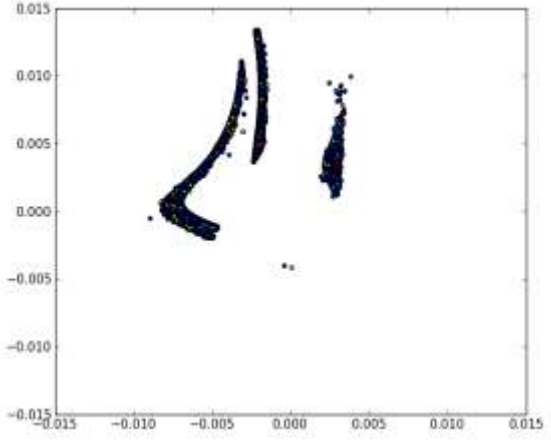


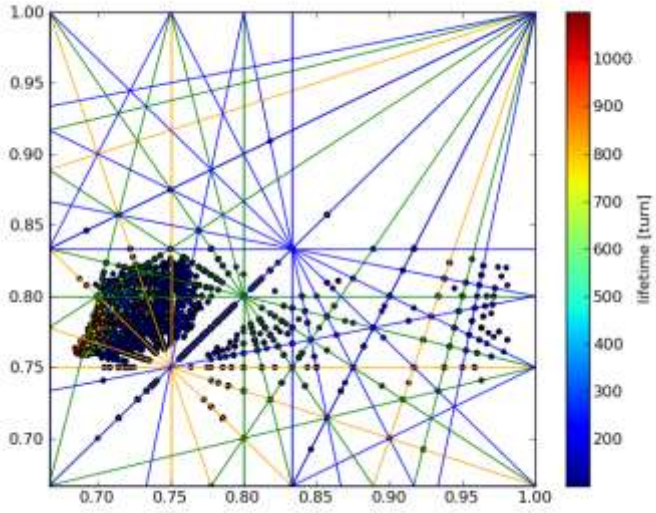
- SC dynamics, lattice optimization, emittance growth, Hoffmann diagnrams, error analysis
- Losses: SC, longitudinal, stripping, black body, collimation system, etc
- F.Ostiguy, N.Solyak, A.Saini, JP.Carneiro, Yu.Eidelman, et al.

Transverse dynamics at extraction



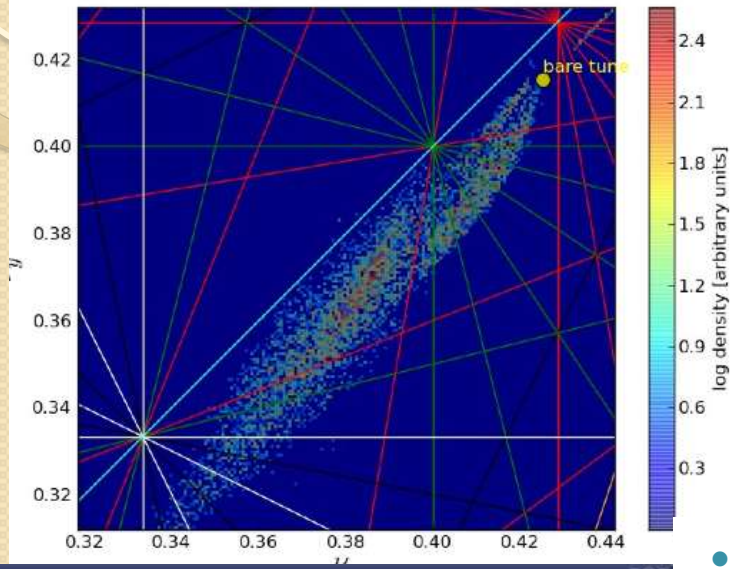


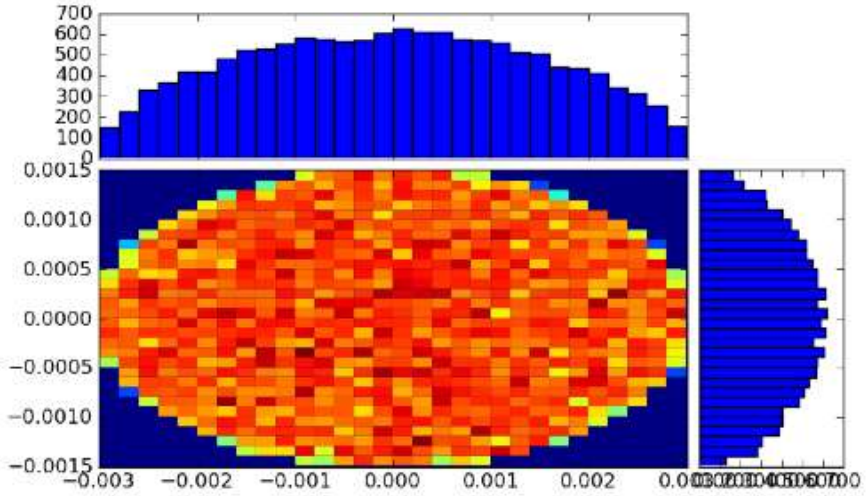


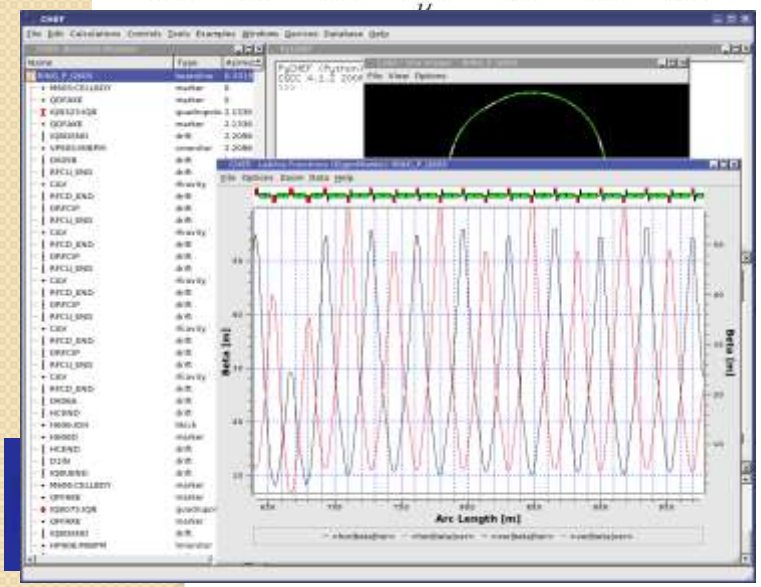


- Next generation experiments (mu2e) require high efficiency extraction of high intensity beams
- Space change and instabilities become of an issue
- Model resonant mu2e extraction including space-charge at the Debuncher :
  - Optimize tune and resonant extraction parameters to minimize losses, understanding dynamics of lost particles, select tunes, etc
- E.Stern, P.Spenzouris, et al.

Space Charge Effects







- In recent past – studies and simulation for Booster (Q_sc~0.3), now for MI (Q_sc~0.1)
- Begin modeling space charge effects and mitigation techniques for Main Injector with Project-X beam parameters
- Extend Synergia to include realistic apertures and fringe fields and study losses and mitigation, if necessary
- E.Stern, P. Spenzouris, et al.

Space Charge Compensation

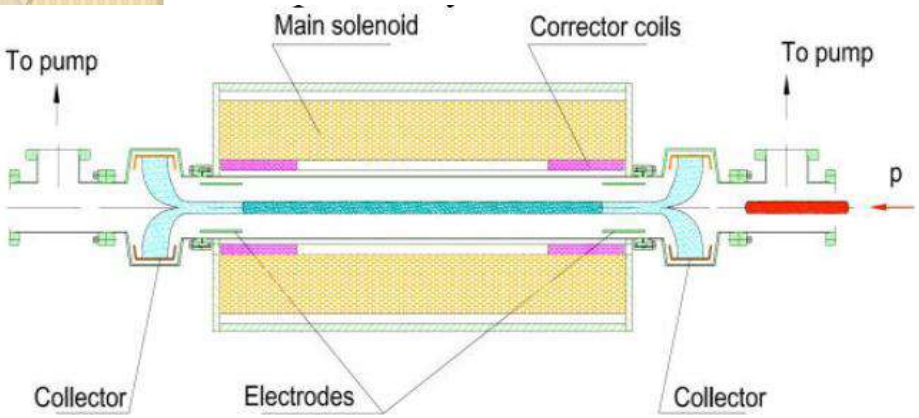
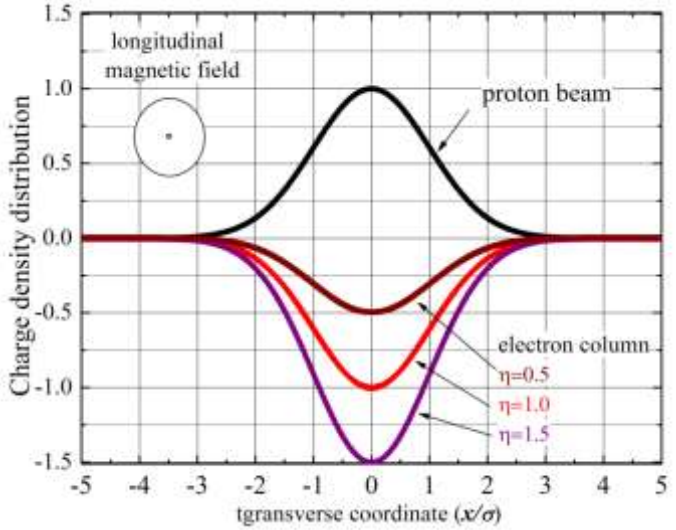
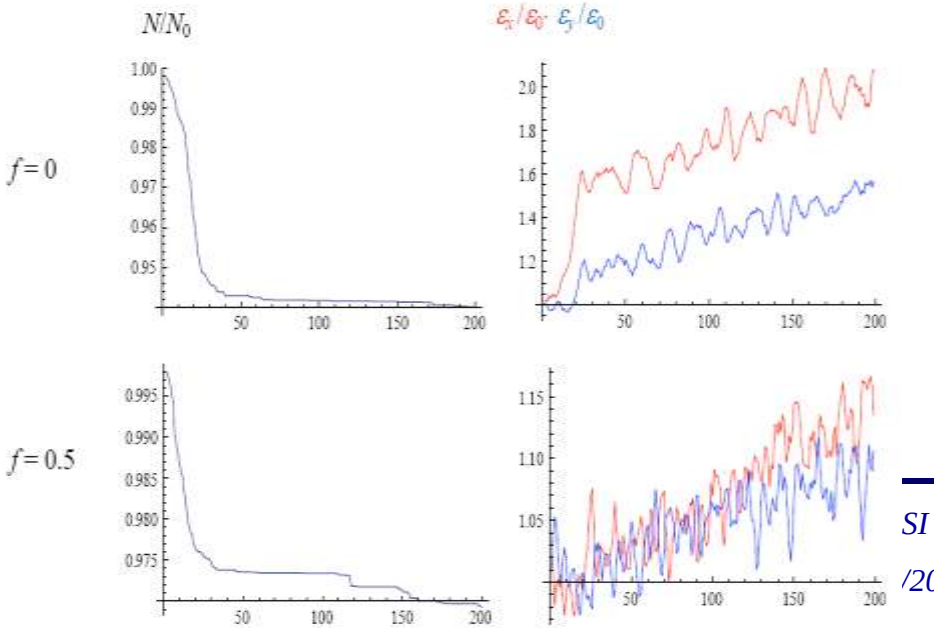


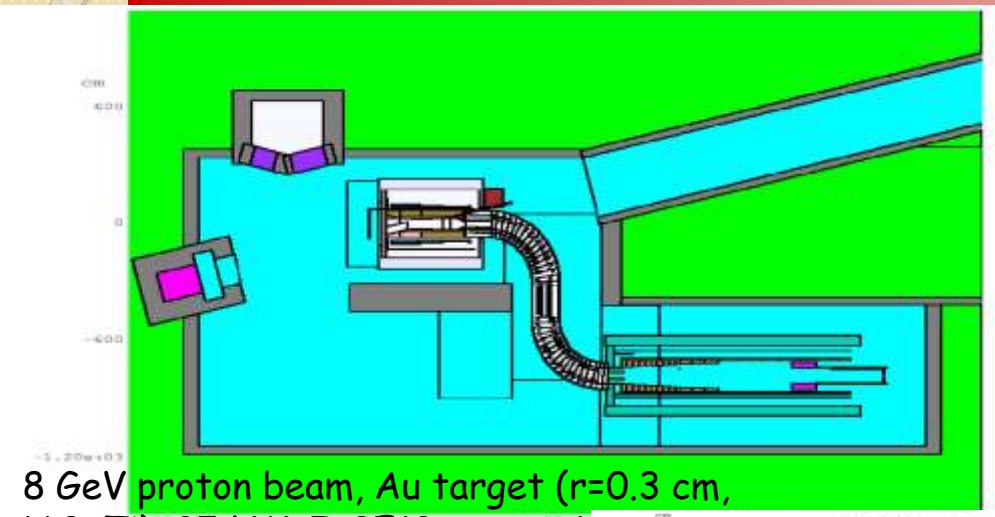
Fig.1. Layout of an "electron column".



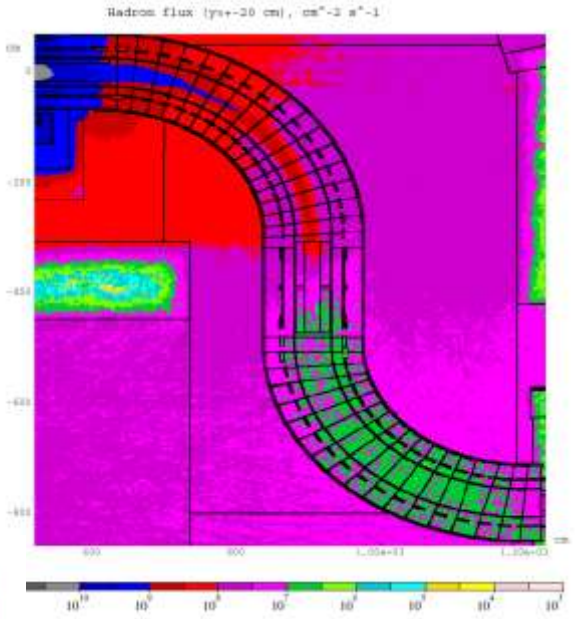


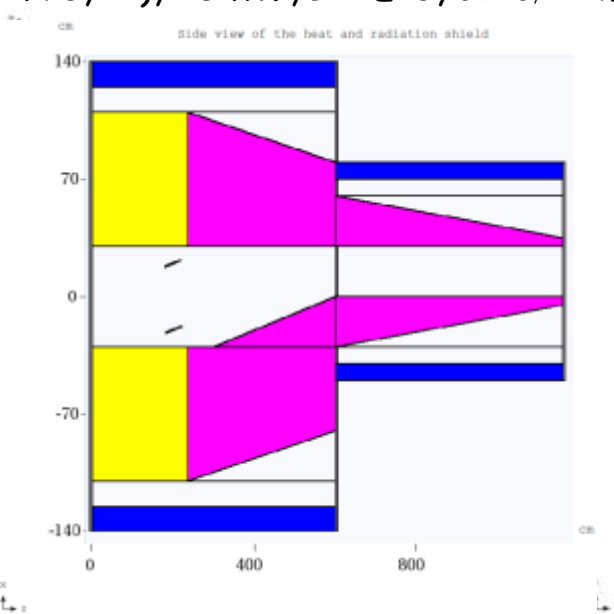
- Compensation by adding 1/gamma^2 magnetized electrons – "e-column"
- Self-consistent simulations for Booster parameters show significant emittance growth reduction with 3-12 columns
- Next step - modeling of possible experiment in MI or/and Recycler and choice of design paramters (B-field, voltages, rotating ExB, etc)
- Yu.Alexahin, V.Kapin, V.Shiltsev, et al.

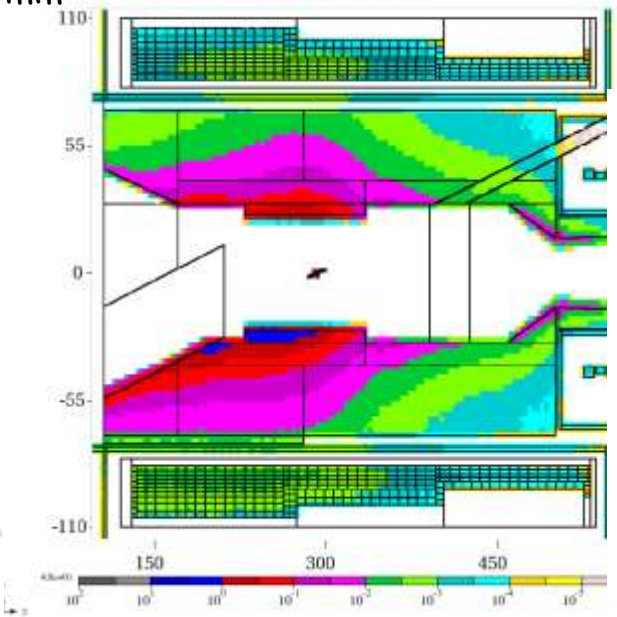
Radiation background: mu2e



8 GeV proton beam, Au target (r=0.3 cm, H_2O, Ti), 25 kW, I=2E13, $\sigma_x = \sigma_y = 1$ mm

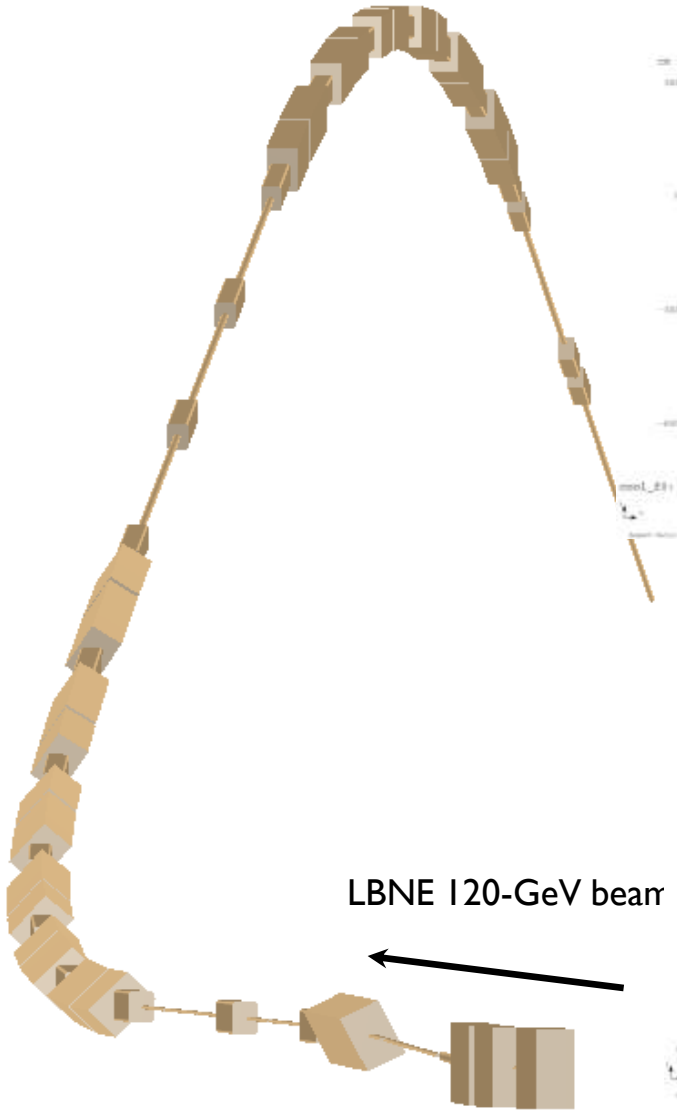


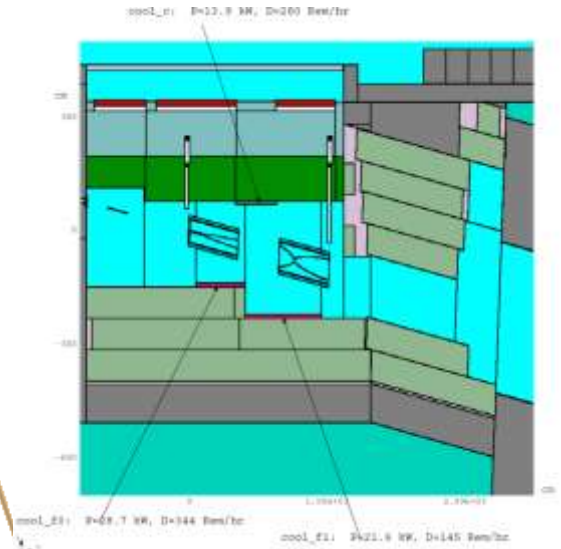


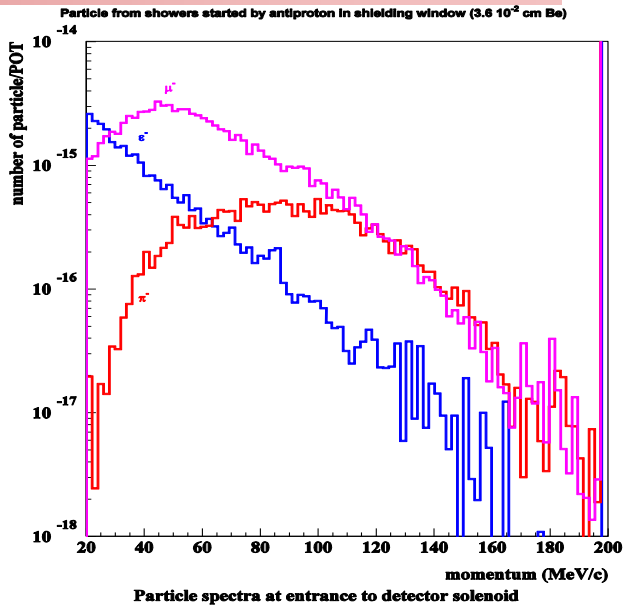


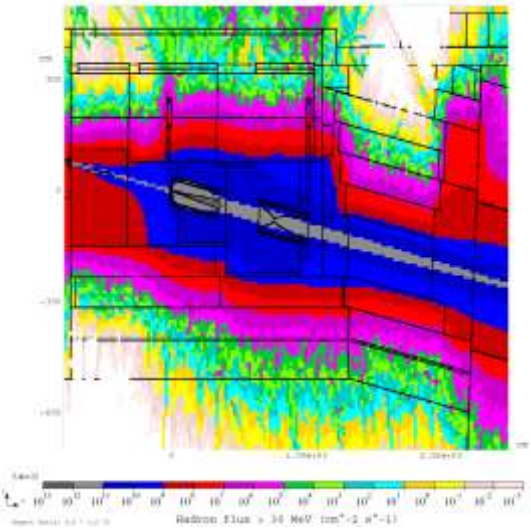
- From mechanical model of the components to source analysis to simulations of radiation levels, heat deposition, etc
- Input to design of magnets, absorbers, shields, beam dump
- N.Mokhov, V.Pronskikh, S.Striganov, et al.

Targets, production, beamlines: LBNE, mu2e, PrX, MC, etc



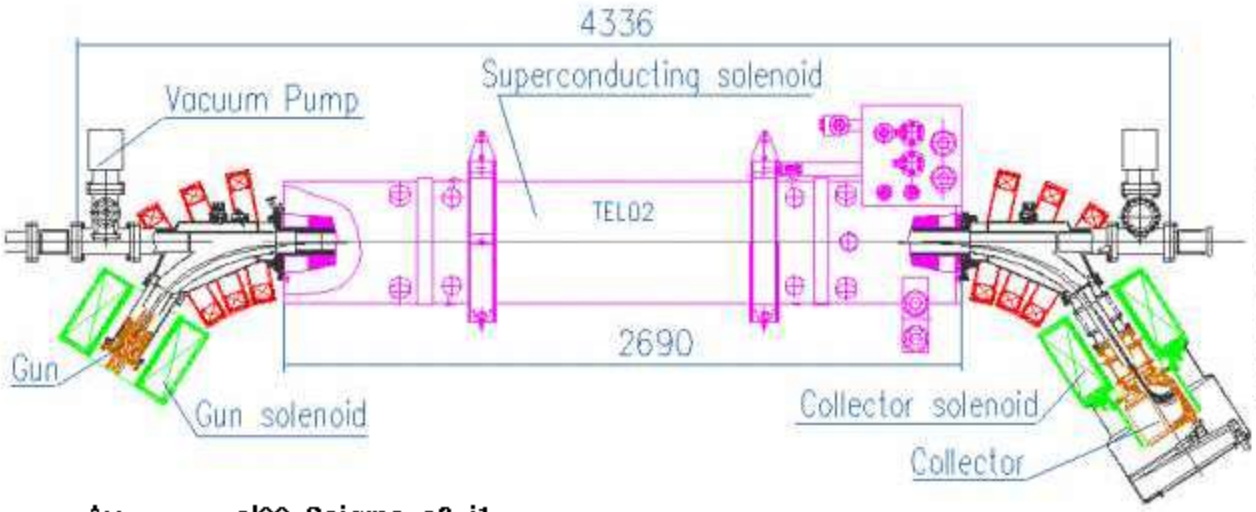


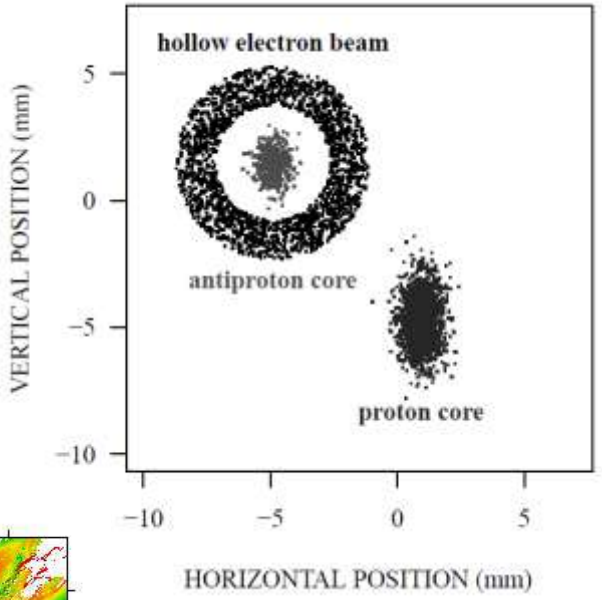


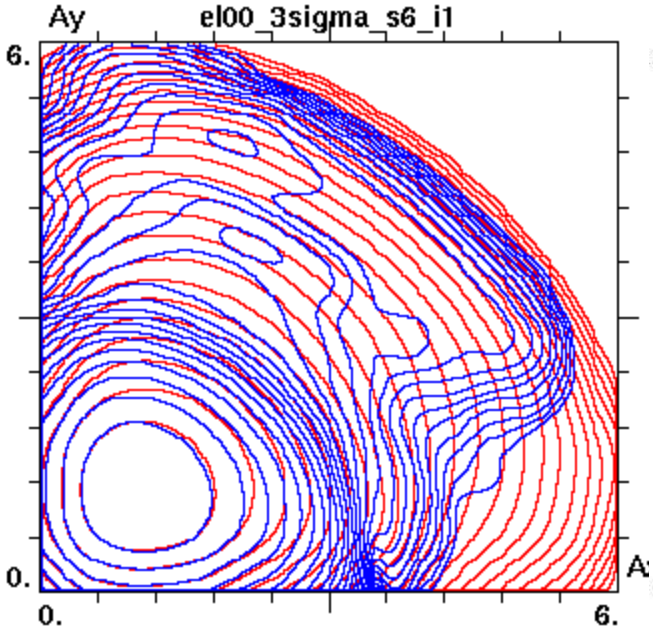


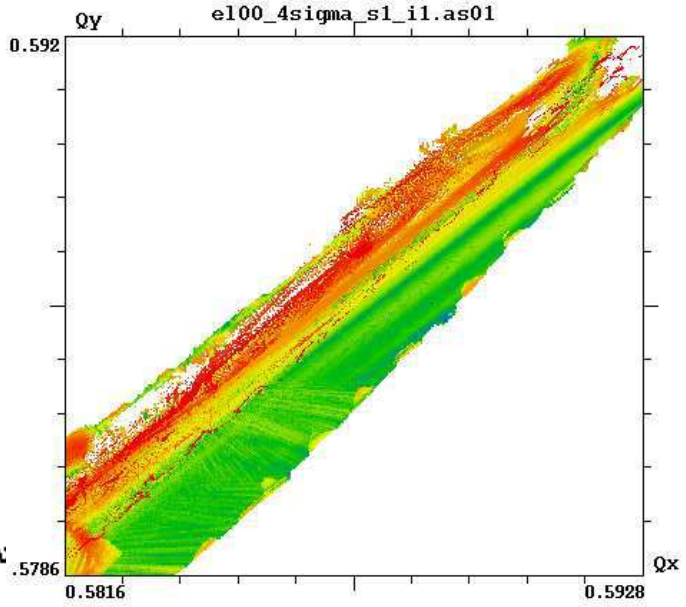
- Production of pions, muons, electron, neutrons, etc
- Realistic environm,ent
- Careful accounting of recent experimental results (HARP - low energy production)
- N.Mokhov, S.Striganov, J.Johnstone, J.Strait, et al.

Hollow E-beam Collimation



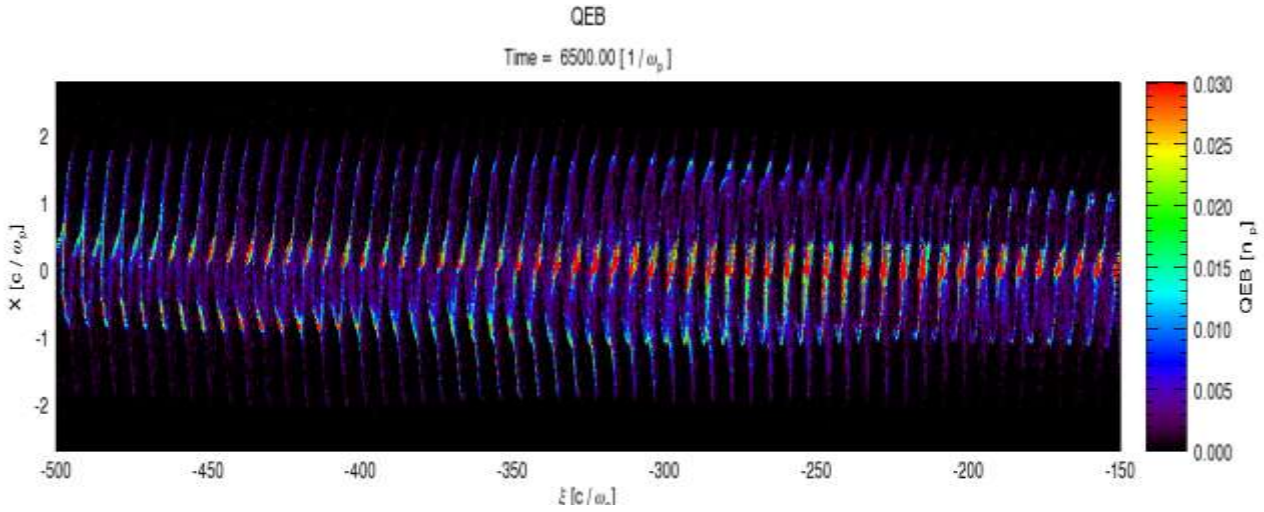


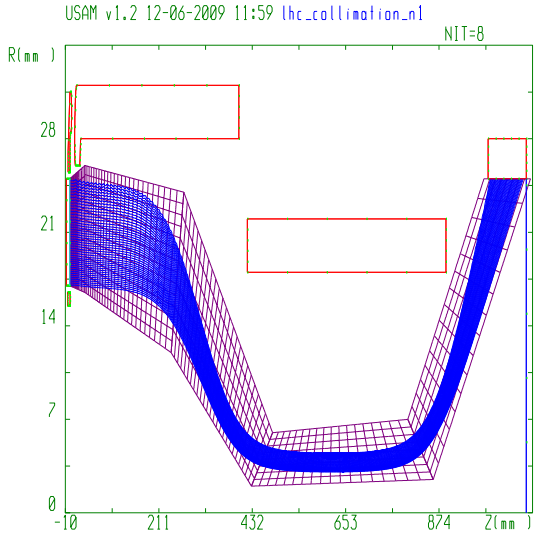


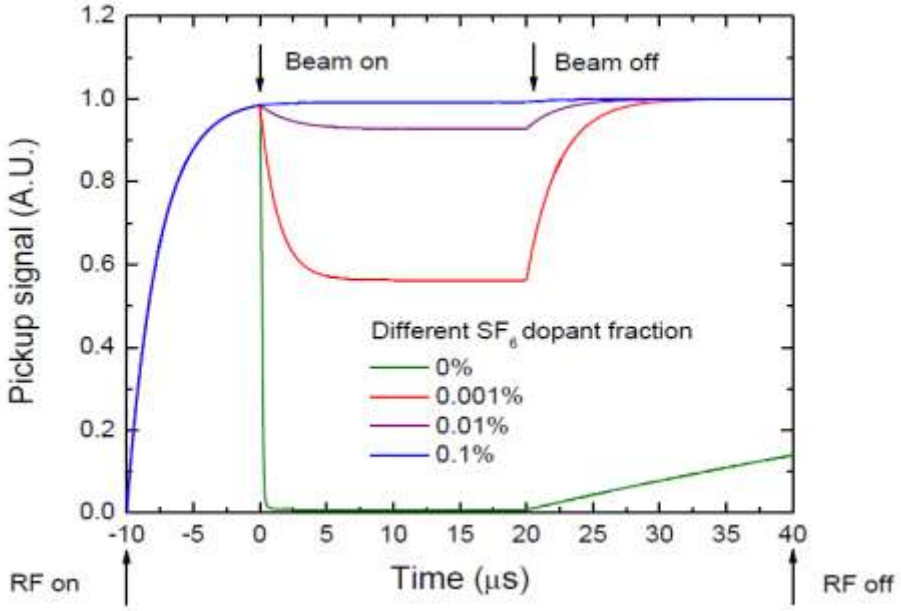


- New method collimation: Tevatron → LHC
- Simulation to explain results of Tev studies (lifetime, FMA tune scan, etc)
- A. Valishev, V. Previtali, I. Morozov, et al.

Modeling/Simulations of sources/plasma







- Variety of tools to simulate beam sources, beam plasme interaction, etc: QUICK-PIC, UltraSAM, etc
- Currently being applied (bottom left to right) to HP RF, Proton plasma acceleartion, electron gun simulations
- M.Chung, A.Tolelstrup, L.Vorobiev, C.Thangaraj, P.Spentzouris, et al.

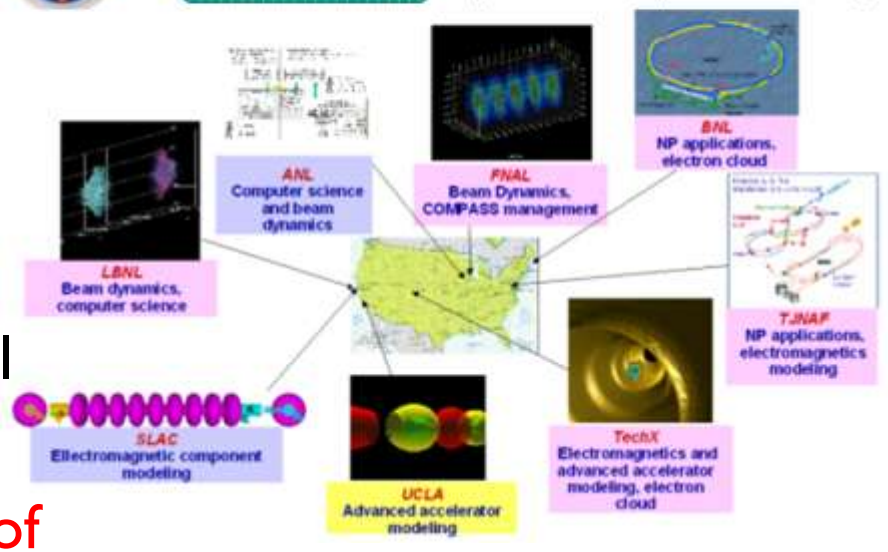
Accelerator Modeling: Programs, Codes

*Community Project for Accelerator Science and Simulations

SciDAC Scientific Discovery through Advanced Computing

https://compass.fnal.gov/

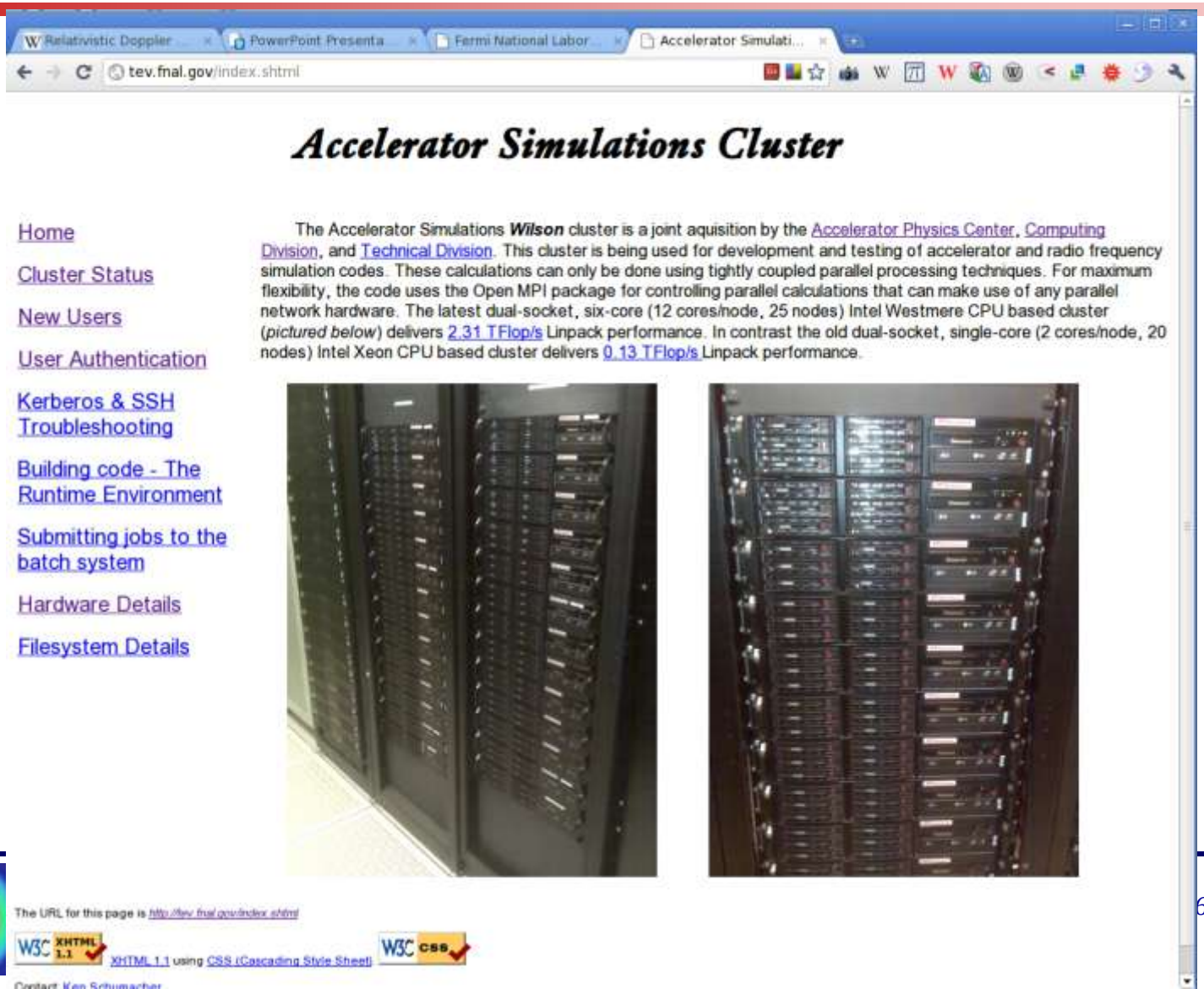
- Fermilab leads the SciDAC2 **ComPASS** project(P.Spentsouris), which aims to develop HPC accelerator modeling tools for
  - BD: multi-physics, multi-scale
  - Design: EM, thermal, mechanical
  - $3M/year OHEP, ASCR, NP, BES
- Support and Develop MARS suite of tools for ED simulation (N.Mokhov)
- Other "Fermi-made" codes: CHEF, OPTIM (optics), SYNERGIA (general)



MARS Code System

http://www-ap.fnal.gov/MARS/
300 official users worldwide

Accelerator Modeling: Infrastructure



Summary

- There are many accelerator modeling / simulation programs and activities covery broad range of issues and applicable to many machines and projects :
  - *Tevatron, Booster, Main Injector, RR, mu2e, LHC, Project X, Muon Collider, etc*
- Fermilab supports development and application of several modeling tools/packages:
  - *SYNERGIA, MARS, OPTIM, CHEF, GEANT4BL, etc*
- We collaborate with several US Nat'l labs &companies
- Potential areas for UK-US/FNAL collaboration:
  - *Project X design, p-source modeling, target ED, SC(C), MAP, FFAG, etc*